AD-A104 433 CLARKSON COLL OF TECHNOLOGY POTSDAM NY F/G 4/1
MICRODOSIMETRIC MEASUREMENTS ON NUCLEAR INTERACTIONS.(U)
JUL 81 P J MCNULTY N00014-81-K-2011
UNCLASSIFIED NL

1 OF 2
AD
A104433

END
DATE
FILMED
10-81
DTIC

Cont

LEVEL II

(12)

AD A104433

Quarterly Technical Report
Submitted to Naval Research Laboratory

by

Clarkson College of Technology
Division of Research
Potsdam, N. Y. 13676

MICRODOSIMETRIC MEASUREMENTS ON NUCLEAR INTERACTIONS

Period: April 1, 1981 - July 31, 1981

Prepared by: Peter J. McNulty
Professor of Physics
Soc. Sec. No. 087-32-9340
Telephone 315-268-2344

Naval Research Laboratory Contract No. N0014-81-K-2011

Table of Contents

1. Introduction and Background

Microelectronic devices flown in space are exposed to energetic heavy particles in the form of cosmic-ray nuclei[1,2] and trapped protons.[3] The published models of the soft-error phenomena in space attribute the upsets to interactions of energetic charged particles with electrons[1,2,4] or nuclei[3,5-8] of atoms in or near some sensitive volume element or elements in the device. These sensitive regions may, depending on the device type, correspond to the memory or register cells, the reference capacitance elements, bit lines, sense amplifiers or some other circuit structures on the devices. Proposed mechanisms involve the creation of electron-hole pairs in or about the sensitive structure; if enough charge is generated within the sensitive volume to alter the electrical state of the element sufficiently to change its logic state, the result is a soft error. The necessary charge can be generated along the trajectory of the incident particle or along the trajectories of any of the secondary charged particles created through interactions. Since nuclear reactions provide a potential mechanism whereby even the lightly ionizing proton component of the space radiation can induce upsets and because protons are more numerous than any of the heavier cosmic ray nuclei, we initiated a series of experiments to explore the role that energetic particles play in the soft-error phenomena in space. Having demonstrated in earlier studies[3,7,8] that energetic protons could induce upsets in LSI static and dynamic RAM devices, we proposed a microdosimetry study of the single nuclear events induced by protons in thin silicon slabs.

The proposal was to use transmission-type surface-barrier detectors to measure the energy deposition in thin slabs of silicon and determine how the energy deposition varies with proton energy and detector thickness. These measurements would provide data for comparison with theoretical simulation models.

When the model has been thoroughly tested for slabs having thicknesses ranging from a few microns to hundreds of microns, it can be used to make predictions for interactions in volume elements having all dimensions comparable to those of volume elements on LSI and VLSI devices.

For some geometries the detector measurements may be directly comparable. Many LSI devices have sensitive volumes with lateral dimensions which are high multiples of their thickness. The reader is referred to Bradford[9] for a detailed discussion of the distribution of track segments in volume elements having microscopic dimensions. The error introduced by approximating the volume by a slab of the same thickness with infinite surface areas is relatively small for volumes having lateral dimensions at least five times the thickness. Because our own calculations suggest that its nuclear recoil with its short range is an increasingly important contributor both as the dimensions of the volume element decrease and as energy required for an upset increases, we feel that the energy-deposition data for the thinnest detectors may be a reasonable approximation for devices with comparable thicknesses and lateral dimensions at least five times the thickness.

We also proposed to develop computer simulation models used to compare with experimental data in the range of proton energies from 50 to 160 MeV. We feel the model that has been developed is useful for incident proton energies up to 350 MeV.

2. Progress to Date

A series of experiments have been conducted using the Harvard Cyclotron. The experiment and some preliminary results are discussed in Appendix A which is a paper presented at the IEEE Conference on Nuclear and Space Radiation Effects in Seattle. The energies deposited in silicon layers with thicknesses varying from 2.5 to 200 μm have been measured for incident proton energies of 51, 91, 132 and 158 MeV. These measurements have been found to agree within

statistics with the predictions of the simulation model developed by us under this DNA contract for 2.5 and 100 μm thickness as illustrated in Fig. 3 of Appendix A. The event rate for single-event depositions exceeding thresholds of from 2 to 8 MeV in a 4.1 μm thick layer increase with increasing incident proton energy in a manner very similar to the dependence on proton energy exhibited by the soft-error cross section measured previously. For the reader's convenience the figures published for the soft-error cross sections and the energy deposition data are presented as Figs. 1 and 2.

3. In Progress

The experiment is being modified to allow considerable increase in statistics, perhaps by a factor of 100. We expect to complete this and to perform some irradiations on the current contract. We are also preparing papers on the simulation model. We are submitting a renewal proposal to DNA through NRL under separate cover. We propose to extend both the experimental technique and the computer model to higher incident proton energies. The model should also be modified to calculate the energy-deposition rates for volume elements exposed to the energetic particles at a variety of locations in space.

4. Talks Presented and Papers Submitted for Publication Under This Contract

1. "Proton-Induced Nuclear Reactions in Silicon", P.J. McNulty, G.E. Farrell, and W.P. Tucker, IEEE Conf. on Nuclear and Space Radiation Effects, Seattle Washington, July, 1981; submitted for publication in the December issue of IEEE Transactions on Nuclear Science.

5. References

1. D. Binder, E.C. Smith, and A.B. Holman, "Satellite Anomalies from Cosmic Rays", IEEE Trans. Nucl. Sci. NS-22, 2675-2680 (1975).

2. J.C. Pickel and J.T. Blandford, "Cosmic-Ray-Induced Errors in MOS Memory Cell", IEEE Trans. Nucl. Sci. NS-25, 1166-1167 (1978).

3. P.J. McNulty, R.C. Wyatt, G.E. Farrell, R.C. Filz, and P.L. Rothwell, "Proton Upsets in LSI Memories in Space", in Space Systems and their Interactions with the Earth's Space Environment (American Institute of Aeronautics and Astronautics, New York, 1980) pp 413-433.

4. L.L. Sivo, J.C. Peden, M. Brettschneider, W. Price, and D. Pentecost, "Cosmic-Ray-Induced Soft Errors in Static MOS Memory Cells", IEEE Trans. Nucl. Sci. NS-26, 5042-5047 (1979).

5. C.S. Guenzer, E.A. Wolicki, and R.G. Allas, "Single Event Upset of Dynamic RAMs by Neutrons and Protons", IEEE Trans. Nucl. Sci. NS-26, 5048-5052 (1979).

6. E.S. Guenzer, R.G. Allas, A.B. Campbell, J.M. Kidd, E.L. Petersen, N. Seeman, and E.A. Wolicki, "Single Event Upsets in RAMs Induced by Protons at 4.2 GeV and Protons and Neutrons below 100 MeV", IEEE Trans. Nucl. Sci. NS-27, 1485-1489 (1980).

7. R.C. Wyatt, P.J. McNulty, P. Toumbas, P.L. Rothwell, and R.C. Filz, "Soft Errors Induced by Energetic Protons", IEEE Trans. Nucl. Sci. NS-26, 4905-4910 (1979).

8. P.J. McNulty, G.E. Farrell, R.C. Wyatt, P.L. Rothwell, R.C. Filz, and J.N. Bradford, "Upset Phenomena Induced by Energetic Protons and Electrons", IEEE Trans. Nucl. Sci. NS-27, 1516-1522 (1980).

9. J.N. Bradford, "A Distribution Function for Ion Track Lengths in Rectangular Volumes", Journal of Appl. Phys. 50, 3799-3801 (1979).

APPENDIX A

PROTON-INDUCED NUCLEAR REACTIONS IN SILICON

Peter J. McNulty and Gary E. Farrell
Department of Physics
Clarkson College of Technology
Potsdam, New York 13676

William P. Tucker
Physics Department
Florida A and M University
Tallahassee, Florida 32307

ABSTRACT

Measurements of the energy deposited in silicon surface-barrier detectors as a result of proton-induced nuclear reactions were carried out at the Harvard Cyclotron for protons with incident energies ranging from 50 to 158 MeV and detectors with thicknesses of 2.5, 4.2, 24.1, 100, and 200 μm. The number of events in which a given threshold amount of energy is deposited in a 4.2 μm detector varied with incident proton energy in a manner similar to previous measurements of the proton-induced soft-error cross section. The number of events in which at least a threshold amount of energy was deposited in the detector fell off in a near exponential manner with increasing threshold energy. The data were found to be in reasonable agreement with a computer simulation model developed in our laboratory. The model is used to illustrate how the mass spectra of the residual nuclear fragments shifts towards lower masses with increasing recoil energy. Lighter recoils have larger ranges and a greater chance of leaving a microscopically thin sensitive volume element before coming to their end of range.

INTRODUCTION

The nuclear interaction provides a mechanism whereby an energetic lightly ionizing particle or non-ionizing neutron can deposit a large amount of energy within a volume element that has microscopic dimensions. The incident particle interacts with one of the nuclei of the material in or about the target volume. Most of the energy deposition takes the form of ionization loss along the trajectories of the charged secondary particles emerging from the "struck" nucleus and along the trajectory of the recoiling residual nuclear fragment. Large numbers of electron-hole pairs are generated as a result of this ionization loss. If such a nuclear event takes place within or near one of the sensitive elements on a large scale integrated (LSI) RAM memory device and sufficient charge is generated the result can be a change in the logic state of the memory element. The alteration of information stored at some location in memory without observable physical damage to the device is called a soft error or bit upset.

Energetic protons have been shown to induce soft errors in a number of LSI dynamic and static RAM devices,[1-5] presumably through (p.α) reactions at low proton energies[1,6,7] and more complex reactions at higher energies.[2,5,8] Besides providing a potential mechanism for soft errors in space, proton-induced nuclear reactions have been proposed to explain anomalous signals observed in Defense Meteorological Satellite Program (DMSP)[9] and LANDSAT satellite systems[10] as well as the light flashes observed by astronauts on Skylab.[11,12]

This paper describes a study of nuclear interactions using silicon surface-barrier detectors of varying thickness ranging from 2.5 to 200 μm. The objective of the study is to provide data on the deposition of energy in volume elements having microscopic dimensions as an aid to developing models capable of predicting event rates to be expected for devices of different geometries exposed to protons with a given energy distribution. Some preliminary results on 24.1 μm thick

detectors were included in last year's paper.[5]

SURFACE BARRIER DETECTORS

Figure 1 shows a schematic cross section of a thin transmission-type silicon surface-barrier detector. The front and back surfaces are 400 μgm/cm^2 layers of gold and aluminum, respectively. They provide the electrical contacts of the detector and voltage applied across them (bias) results in a uniform field through the silicon slab. Each detector used in this study was run at sufficient bias to ensure that the detector volume was fully depleted. The charge generated within the slab from ionization-loss processes is swept by the applied field to the electrodes. The silicon slab portions of the detector varied in thickness from 2.5 to 200 μm. The thickness and area of each detector used are listed in Table 1. Energetic protons incident normal to the detector may interact with nuclei in the silicon slab, in one of the contacts or in the air. Only in the thinnest detectors do a significant fraction of the interactions occur outside the silicon slab.

Only those segments of the trajectories of the secondary particles emerging from the interactions that traverse the silicon slab or generate charges that migrate to the slab contribute to the observed signal. Most of the secondary particles emerging from a nuclear interaction in a thin detector leave the silicon slab before depositing significant energy (>2MeV). This is shown schematically in Fig. 1. The exception is the nuclear recoil. The recoiling nuclear fragments have short range most can be expected to deposit their entire energy within all but the thinnest detectors.

The question arises as to whether energy-deposition measurements using these detectors with their relatively large sensitive areas (25 mm^2) provide data that are relevant to energy deposition in the sensitive volumes of LSI devices where three dimensions are microscopic instead of one. First, the data obtained with detectors

can be directly compared with models[13,14] which attempt to calculate the energy deposition spectra for volume elements of arbitrary size and shape. These models can then be used to calculate for volumes with dimensions appropriate for a given device. Second, many LSI devices have sensitive volumes whose lateral dimensions are high multiples of their thickness. The reader is referred to Bradford's paper[15] for a detailed discussion of the distribution of track segments in volume elements and the approximations involved. Because our own calculations suggest that the nuclear recoil with its short range is an increasingly important contributor as the dimensions of the volume element decrease and the threshold energy increases, we feel that the energy deposition data from the thinnest detectors may be a reasonable approximation for LSI devices with comparable thicknesses and lateral dimensions at least five times the thickness.

IRRADIATIONS

The proton exposures were carried out at the Harvard Cyclotron. The experimental configuration used for these exposures is shown in Fig. 2. The beam energy was selected by inserting appropriate degraders upstream. This report includes data from exposures to protons at 51, 91, 131, and 158 MeV. The beam incident on the detector was collimated by the two defining apertures. It was collimated to 2 mm in diameter for all but the 2.5 μm thick detector. For the latter the beam was uniform over dimensions considerably larger than the detector. When the beam is collimated to 2 mm, most of the beam protons emerging from the cyclotron interact in the collimator walls or the degrader blocks. This generates a considerable background of secondary particles. After each exposure was completed a second run was carried out with the downstream aperture replaced by a beam plug. The plug prevents any primaries from reaching the detector. The plug-in runs were used to provide an estimate of background due to interactions that occur outside the detector.

The 2 mm beam exposures were monitored by two scintillators, one just downstream of the detector and a second upstream between the first and second apertures. Plug-in and plug-out runs were carried out for the same number of counts on the upstream scintillator. The data presented in the paper have the plug-in spectra subtracted.

The 2.5 μm detector was monitored by a ionization chamber upstream of the detector. This allowed us to increase the beam count rate from slightly less than 10^6 protons/minute to about 10^9 protons/minute. This was advantageous because of the sharp decrease in event rate in which more than a few MeV are deposited as the detectors become thinner.

Pulses in the bias voltage across the detector were shaped and suitably amplified in an Ortec 172B charge-sensitive preamplifier and an Ortec 450 amplifier before being recorded in a multichannel analyzer. The pulses should be proportional to the energy deposited by the beam protons entering the detector and any secondary particles generated through interactions inside or outside the detector. The detecting systems were calibrated before and after the experiment with a ^{241}Am alpha source and its linearity tested with a pulser. The pulse-height spectra obtained with the surface-barrier detectors minus plug-in background should then represent the spectra of energies deposited in the slab of silicon as a result of nuclear interactions.

PULSE-HEIGHT SPECTRA

The standard models[16-18] of soft errors in RAMs assume that if an amount of energy exceeding some critical or threshold value is deposited within a sen 'tive volume element an upset will occur and the deposition of less than a threshold

amount of energy will not upset the element. This makes it instructive to plot pulse-height spectra as integral spectra, i.e., number of events in which the energy deposited in the slab is greater than or equal to E versus E. Typical integral spectra are plotted in Fig. 3 for 131 MeV protons. The 100 μm detector data are plotted for an exposure of 10^7 scintillation counts. The 200 μm data represent 10^6 counts with the numbers multiplied by a factor of 2. The 4.2 μm data were multiplied by a factor of about 25 to fit them on the scale. The 2.5 μm data were obtained with an ionization chamber monitor but we estimate a scale factor of about 25. No corrections have been made for deadtime or other losses in the scintillation counters and the ordinate scale may underestimate the true fluence. The 24.1 μm detector was only monitored by the upstream scintillator and no absolute estimate of fluence was possible. It was arbitrarily normalized in Fig. 3 for convenient plotting. Squeezing the spectra onto one plot as we did in Fig. 3 facilitates comparison of the shapes and ranges of the spectra, the important parameters for the soft-error problem.

The integral spectra for the 2.5, 4.2, 24.1 and 100 μm spectra in Fig. 3 all appear to fall off near exponentially with the energy deposited. The 200 μm thick detector, on the other hand, exhibits a sharp decrease at low energies and parallels the 100 μm spectra at large energies. The 200 μm detector had a larger area (200 mm^2) than the other detectors (25 mm^2). Plug-in runs showed it to be subject to much greater background from interactions upstream, probably because it presented a larger cross-sectional area for secondaries generated upstream. These secondaries would generate low-energy pulses upon traversing the detector.

The 100 μm and 200 μm spectra illustrate the energies available from nuclear interactions. The largest events for the 100 and 200 μm detectors were 76 and 99 MeV, respectively. Significant fractions of the events deposit 10, 20, 30, and even 40 MeV. Most of this energy is deposited over a volume that is considerably larger than a

typical sensitive volume element on an LSI device. Reducing the thickness of the sensitive volume results in a corresponding reduction in large energy events. Only one event with greater than 40 MeV deposited was obtained with the 25 μm detector. Reducing the thickness further results in a dramatic reduction in large-energy depositions. No events of greater than 20 MeV were seen in an exposure of the 4.2 μm detector to 25×10^7 protons. Therefore, even with sensitive volumes that have only one microscopic dimension, there is a sharp reduction in energy deposition when the thickness of the element is reduced.

VARIATION WITH PROTON ENERGY

The integral spectra of Fig. 3 provide the number of events in which at least some threshold energy E is deposited in each of the detectors as a result of exposure to 10^7 protons incident at 131 MeV. The corresponding number of events exceeding this threshold value can similarly be obtained from the other incident proton energies. The number of events exceeding threshold per 10^7 protons (scintillation counts) is plotted versus incident proton energy for different values of the threshold for the 100 μm thick detector in Fig. 4a and for the 4.2 μm thick detector in Fig. 4b, respectively. In the case of the 100 μm detector the number of events for a given threshold increases with beam energy for threshold values from 2 to 45 MeV. Small changes in threshold result in correspondingly small changes in the number of events. The 4.2 μm data in Fig. 4b, on the other hand, shows evidence of peaking at 131 MeV for threshold energies from 5 to 8 MeV. Moreover, small changes in threshold result in substantial changes in the number of events - an increase in threshold of 1 MeV reduces the number by a factor of 2. The variation with incident beam energy exhibited by the 4.2 μm detector in Fig. 4b is similar in shape to the curves for soft-error cross sections versus proton energy presented in Ref. 2 for LSI dynamic RAMs. The considerable variation among devices among the same type reported in Ref. 2 may according to this analysis be due to

relatively small variations in the critical charge (or energy) necessary for an upset.

MODEL CALCULATIONS

We have recently developed a computer code for calculating the energy deposited in parallelpiped volume elements of arbitrary dimensions. It is based on the simulation model of nuclear interactions developed by Metropolis et al.[19] and Dostrovsky et al.[20]

The primary protons and all struck nucleons are followed by Monte Carlo routines through a series of interactions within the nucleus. All secondary particles that emerge from the excited residual nucleus during the cascade and evaporation processes are followed to their end of range. The numbers of each type of secondary particle and their energy spectrum, were compared with Refs. 19 and 20 to test the program and found to be in agreement. The mass-number spectrum of the residual nuclei were compared with Silberberg and Tsao[21] for 130 MeV protons incident on silicon and found to predict similar mass spectra within $\pm$ 1 AMU. Their recoil energy spectra were found to agree with an earlier empirical model of the recoiling residual fragments which uses the Silberberg and Tsao mass spectra[21] and Goldhaber's[22] parameterization of the recoil fragment momenta of the data of Heckman et al.[23] The program then determines the points at which any particles enter the sensitive volume element and where they leave (see Fig. 5). Interactions may occur inside or outside the sensitive volume element. The difference in residual range between the exit point and entry point is used to determine the energy loss within the volume element. For the larger volume elements the assumption is made that the energy loss within the volume element equals the energy deposited in that element. The program totals all energies deposited in the volume element by the primary proton, all charged secondaries, and the recoiling nuclear fragment.

Theoretical integral energy deposition spectra for protons incident on slabs of silicon with areas of 25 mm^2 and thicknesses of 24.1 and 100 μm are plotted as solid curves in Fig. 3. The simulation plots are normalized to the lowest energy data points in both cases. The programs continued to run until the number of simulated events roughly matched the experimental number. As a result the high deposition-energy portions of the theoretical as well as experimental spectra have limited statistical significance which can be estimated from the ordinate scale. Within the statistics the fits at both 24.1 and 100 μm are quite encouraging.

We have previously shown that the 24.1 μm spectrum has a shape similar to the energy spectrum of recoiling residual nuclear fragments.[5] The shallower slope of the 100 μm spectrum reflects the larger contribution from other charged secondary particles to the energy deposited. As the thickness of the detectors decrease, the secondaries contribute a correspondingly smaller fraction of the energy. For the very thin detectors even some of the recoiling nuclear fragments leave the detector before reaching their end of range.

RESIDUAL NUCLEAR FRAGMENTS

The large mass of the recoiling residual nuclear fragment implies that it has a very short range. For RAM memory elements, as for the very thin detectors, the nuclear recoil provides a mechanism for depositing energies larger than the threshold values for upsets. However, not all recoils reach their end of range within a few microns of the interaction. The more energetic nuclear recoils tend to occur in interactions where the number of secondary particles emitted from the nucleus is large. This implies residual fragments with less mass, i.e., the more energetic residual nuclei would tend to be lighter than the average and, therefore, have larger ranges. This is illustrated in Fig. 6 which shows the mass spectra of the residual nuclear fragments for nuclear fragments having recoil kinetic energies above 0, 10, 20, and 30 MeV. The spectra are plotted for 90 and 350 MeV protons

incident on silicon. At both incident energies the spectra shift towards lower masses as the minimum energy is increased. The largest shift occurs for values between 0 and 10 MeV.

The interactions at an incident proton energy of 350 MeV are more energetic than at 90 MeV. This is reflected in Fig. 6 by the larger number of energetic fragments and a sizable shift towards lower masses for the same threshold energy. A fragment with a mass of 16 AMU and a kinetic energy of 10 MeV would have a range of about 2.3 μm in silicon; if the kinetic energy was 30 MeV the range would be increased to about 11 μm.

SUMMARY AND CONCLUSIONS

The measurements described in this report provide data on the energy deposition spectra and their dependence on incident particle energy which can be compared with theoretical models of the microdosimetry of nuclear interactions. Once thoroughly tested such a model can be used to predict the energy-deposition spectra for volume elements of arbitrary dimensions. This provides a means of quantitative estimates of the soft-error rates to be expected for LSI and VLSI devices to be exposed to energetic particles in space. The cross section for events in which at least a few MeV is deposited within a sensitive volume 4.2 μm thick increases with the proton beam energy in a manner similar to that reported earlier[2] for soft errors in LSI RAMs. Small increases in the threshold energy result in large decreases in the number of events exceeding threshold in a 4.2 μm thick detector. This may explain the large variation in upset sensitivity reported for devices from the same batch.[2]

Decreases in the thickness of the sensitive volume greatly reduce the range of energies deposited. This suggests that devices with thinner sensitive elements for the same threshold may have greatly reduced soft-error sensitivity. Such a correlation between sensitivity to soft errors and thickness of the sensitive volume

is apparent for exposures to heavy ions.[17,18,24]

A computer code for calculating the energy deposition in volume elements of arbitrary dimensions as a result of nuclear interactions has been developed at Clarkson and shown to agree in shape within statistics with the integrated spectra obtained for 24.1 and 100 μm thick detectors exposed to 131 MeV protons. The model suggests that recoiling nuclear fragments with kinetic energies above 10 MeV have lighter masses and correspondingly longer residual ranges. This may somewhat reduce the effectiveness of the recoil nucleus in inducing upsets in very small sensitive volume elements.

ACKNOWLEGEMENTS

This work was supported in part by the Defense Nuclear Agency. The help of A. Koehler and the staff of the Harvard Cyclotron and C.S. Guenzer of the Naval Research Laboratory are gratefully acknowledged.

FIGURE CAPTIONS

Fig. 1 Schematic of a nuclear reaction occuring in a thin transmission-type silicon surface barrier detector.

Fig. 2 Experimental configuration for exposures carried out at the Harvard Cyclotron. Scintillators mounted behind the detector and upstream between the collimators were used to monitor the beam.

Fig. 3 Integral spectra for energy deposition in thin detectors of various thicknesses for 131 MeV protons. The solid curves are the results of computer simulations carried out to roughly the same statistics. The 2.5 and 4.2 μm data were obtained for fluences 25 x 10^7 protons.

Fig. 4 Number of events per 10^7 incident protons in which at least a threshold amount of energy is deposited in the detector. (a) Curves for threshold energies of 2 to 8 MeV deposited in a 4 μm thick detector. (b) Curves for 2 to 50 MeV deposited in the 100 μm thick detector.

Fig. 5 Schematic of a nuclear interaction occurring near a sensitive volume element. The C.C.T. model calculates the energy deposited in volume elements of arbitrary dimensions.

Fig. 6 Mass spectra of residual nuclear fragments as calculated by the C.C.T. model for 90 and 350 MeV proton interactions with silicon. Spectra are shown fot recoils having greater than 0, 10, 20, and 30 MeV for both incident proton energies.

REFERENCES

1. C.S. Guenzer, E.A. Wolicki, R.G. Allas, "Single Event Upsets of Dynamic RAMs by Neutrons and Protons", IEEE Trans. Nucl. Sci. NS-26, 5048-5052 (1979).

2. R.C. Wyatt, P.J. McNulty, P. Toumbas, P.L. Rothwell, and R.C. Filz, "Soft Errors Induced by Energetic Protons", IEEE Trans. Nucl. Sci. NS-26, 4905-4910 (1979).

3. C.S. Guenzer, R.C. Allas, A.B. Campbell, J.M. Kidd, E.L. Petersen, N. Seeman, and E.A. Wolicki, "Single Event Upsets in RAMs Induced by Protons at 4.2 GeV and Protons and Neutrons below 100 MeV", IEEE Trans. Nucl. Sci. NS-27, 1485-1489 (1980).

4. W.E. Price, D.K. Nichols, and K.A. Soliman, "A Study of Single Event Upsets in Static RAMs", IEEE Trans. Nucl. Sci. NS-27, 1506-1508 (1980).

5. P.J. McNulty, G.E. Farrell, R.C. Wyatt, P.L. Rothwell, R.C. Filz, and J.N. Bradford, "Upset Phenomena Induced by Energetic Protons and Electrons", IEEE Trans. Nucl. Sci. NS-27, 1516-1522 (1980).

6. E.L. Petersen, "Nuclear Reactions in Semiconductors", IEEE Trans. Nucl. Sci. NS-27, 1494-1499 (1980).

7. J.N. Bradford, Air Force Report RADC TR-79-109, May 1978.

8. P.J. McNulty, R.C. Wyatt, G.E. Farrell, R.C. Filz, and P.L. Rothwell, "Proton Upsets in LSI Memories in Space" in Space Systems and Their Interactions with the Earth's Space Environment, H.B. Garrett and C.P. Pike, Eds (American Institute of Aeronautics and Astronautics, New York 1980), pp. 413-433.

9. R.C. Filz and L. Katz, "An Analysis of Imperfections in DMSP Photographs Caused by High Energy Solar and Trapped Protons", Air Force Report AFCRL-TR-74-0469, September 1974.

10. T.A. Croft, "Nocturnal Images of the Earth from Space", Stanford Research Institute Report No. 68197, March 1977.

11. P.L. Rothwell, R.C. Filz, and P.J. McNulty, "Light Flashes Observed on Skylab 4: The Role of Nuclear Stars", Science 193, 1002-1003 (1976).

12. P.J. McNulty, V.P. Pease, V.P. Bond, R.C. Filz, and P.L. Rothwell, "Particle-Induced Visual Phenomena in Space", Radiation Effects 34, 153-156 (1977).

13. J.N. Bradford, "Single Event Error Generation by 14 MeV Neutron Reactions in Silicon", Trans. IEEE Nucl. Sci. NS-27, 1480-1484 (1980).

14. G.E. Farrell and P.J. McNulty, to be published.

15. J.N. Bradford, "A Distribution Function for Ion Track Lengths in Rectangular Volumes", Journal of Appl. Phys. 50, 3799-3801 (1979).

16. D. Binder, E.C. Smith, and A.B. Holman, "Satellite Anomalies from Cosmic Rays", IEEE Trans. Nucl. Sci. NS-22, 2675-2680 (1975).

17. J.C. Pickel and J.T. Blandford, "Cosmic-Ray-Induced Errors in MOS Memory Cell", IEEE Trans. Nucl. Sci. NS-25, 1166-1167 (1978).

18. L.L. Sivo, J.C. Peden, M. Brettschneider, W. Price, and D. Pentecost, "Cosmic-Ray-Induced Soft Errors in Static MOS Memory Cells", IEEE Trans. Nucl. Sci. NS-26, 5042-5047 (1979).

19. N. Metropolis, R. Bivins, M. Storm, A. Turkevich, J.N. Miller, and G. Friedlander, "Monte Carlo Calculations on Intranuclear Cascades I. Low-Energy Studies", Phys. Rev. 185-219

20. L. Dostrovsky, Z. Fraenkel, and G. Friedlander, "Monte Carlo Calculations of Nuclear Evaporation Processes III. Applications to Low-Energy Reactions", Phys. Rev. 116, 683-702 (1959).

21. R. Silberberg and C.H. Tsao, "Partial Cross Sections in High Energy Nuclear Interactions and Astrophysical Applications I. Targets with $Z \leq 28$", Astrophysical Journal Supplement. 25, 315 (1973).

22. A.S. Goldhaber, "Statistical Models of Fragmentation Process", Phys. Lett. 53B, 306-308 (1974).

23. H.H. Heckman, D.E. Greiner, P.J. Lindstrom, and H. Shwe, "Fragmentation of ^{4}He, ^{12}C, ^{14}N, and ^{16}O Nuclei in Nuclear Emulsion at 2.1 GeV/Nucleon", Phys. Rev. 17, 1735-1747 (1978).

24. W.A. Kolasinski, J.B. Blake, J.K. Anthony, W.E. Price, and E.C. Smith, "Simulation of Cosmic-Ray Induced Soft Errors and Latchup in Integrated-Circuit Computer Memories", IEEE Trans. Nucl. Sco. NS-26, 5087-5091 (1979).

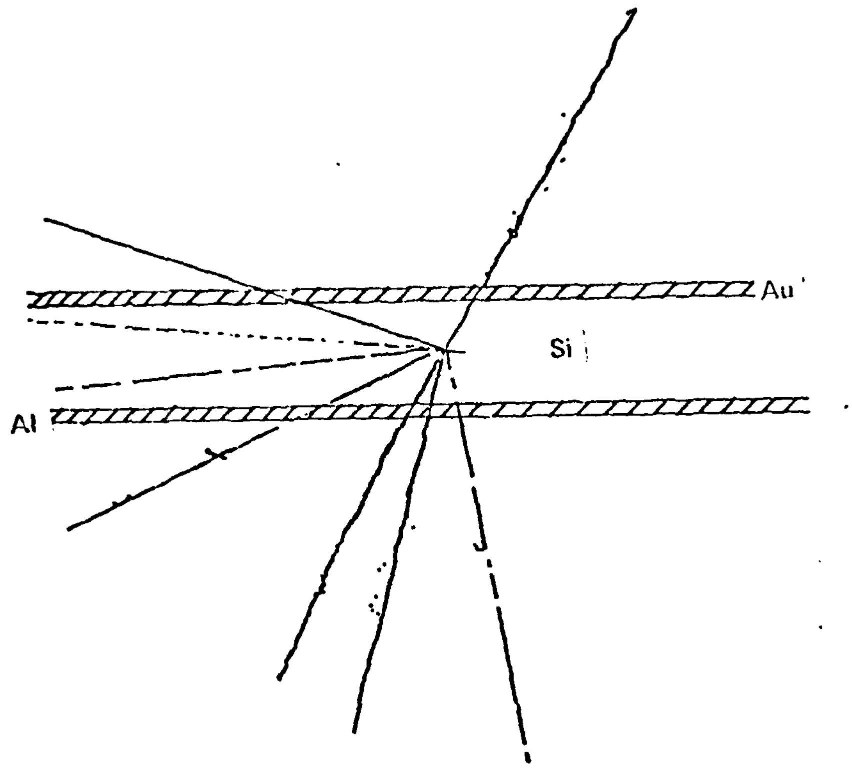
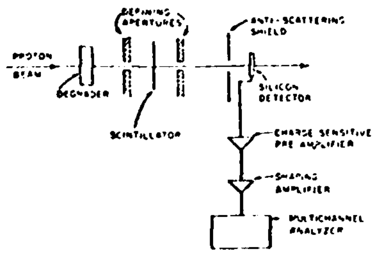
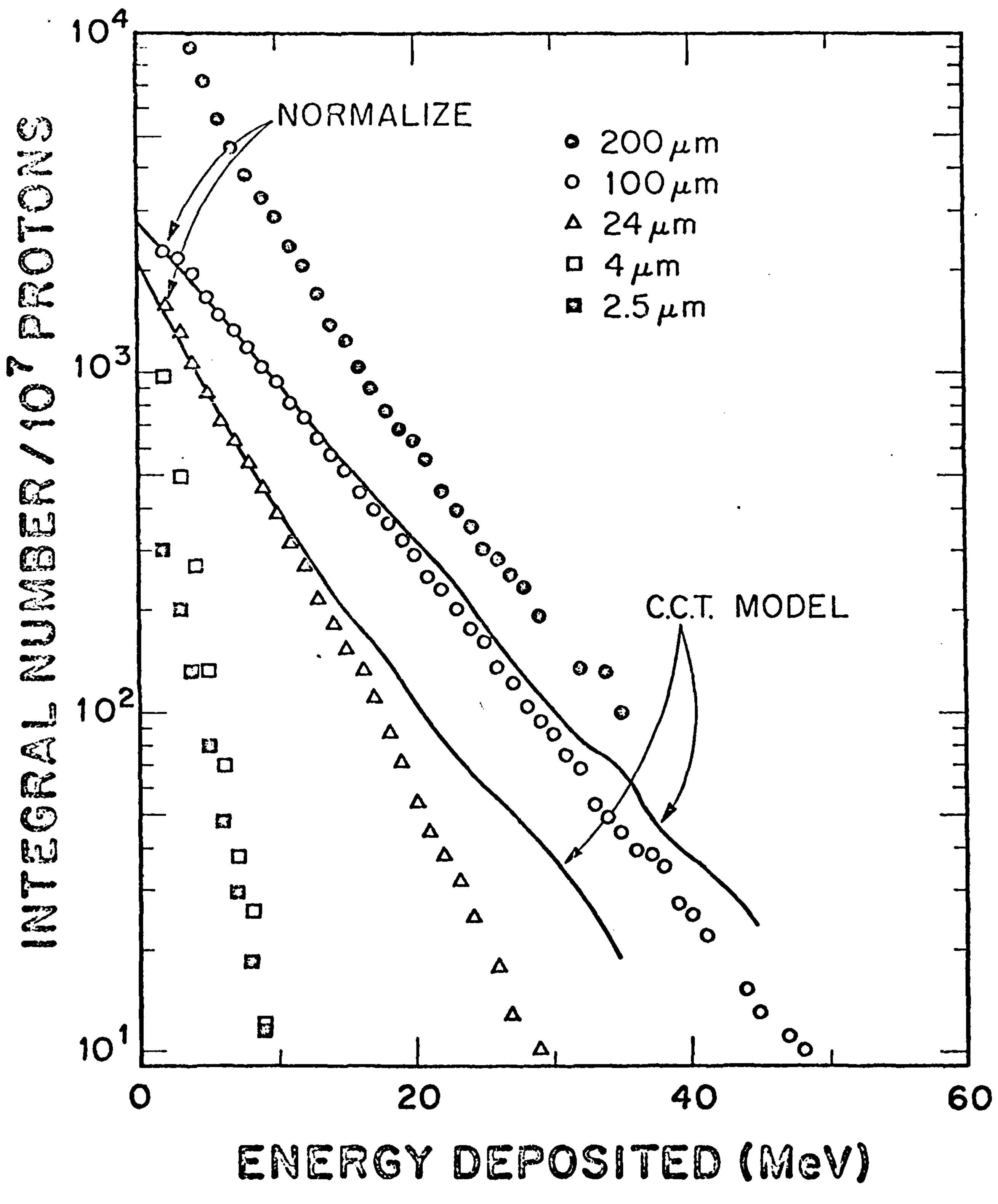


Fig. 1



DEFINING APERTURES
ANTI-SCATTERING SHIELD
PROTON BEAM
DEGRADER
SILICON DETECTOR
SCINTILLATOR
CHARGE SENSITIVE PRE AMPLIFIER
SHAPING AMPLIFIER
MULTICHANNEL ANALYZER

Fig. 2



10^4
10^3
10^2
10^1
NORMALIZE
200 μm
100 μm
24 μm
4 μm
2.5 μm
C.C.T. MODEL
0
20
40
60
INTEGRAL NUMBER / 10^7 PROTONS
ENERGY DEPOSITED (MeV)

Fig. 3

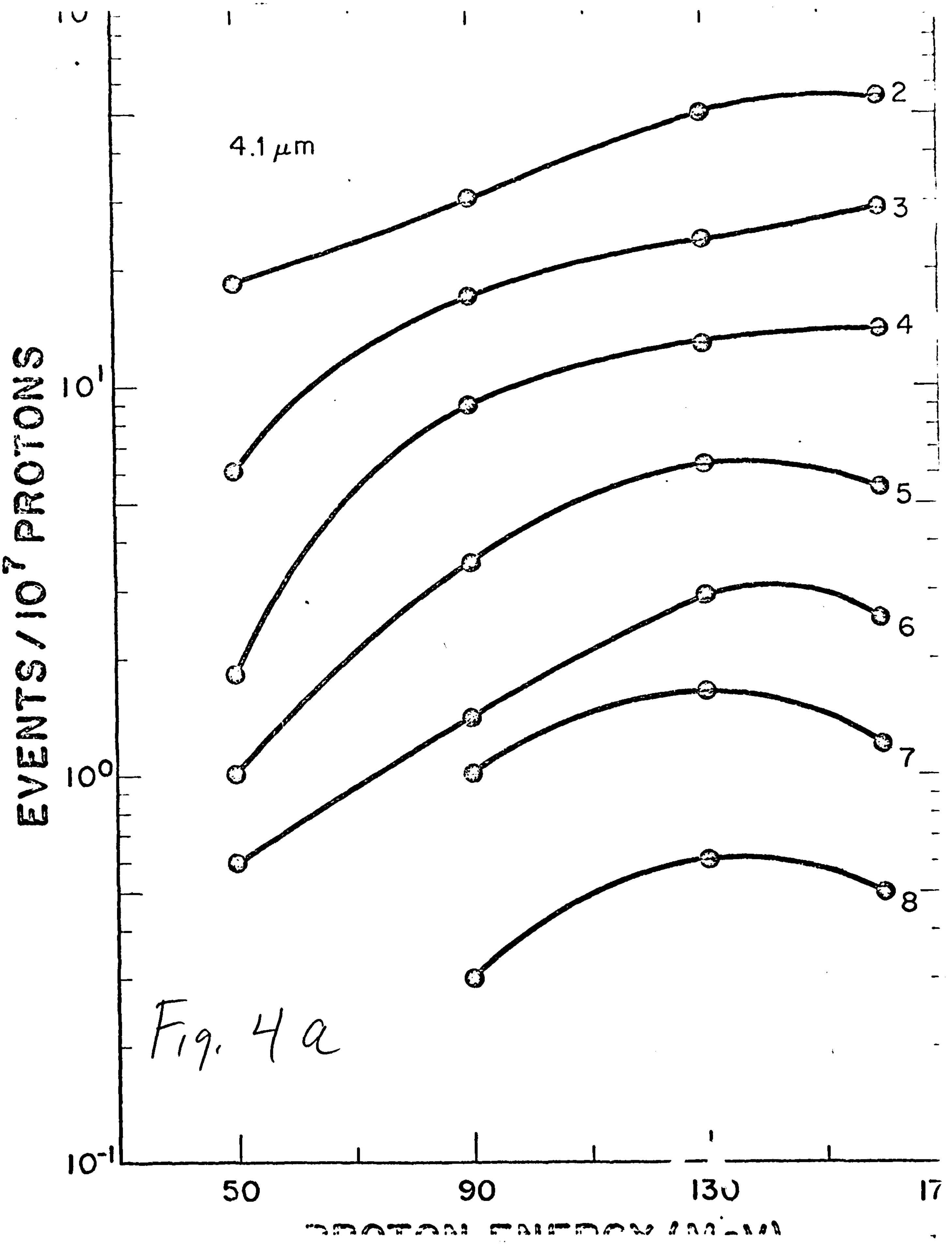
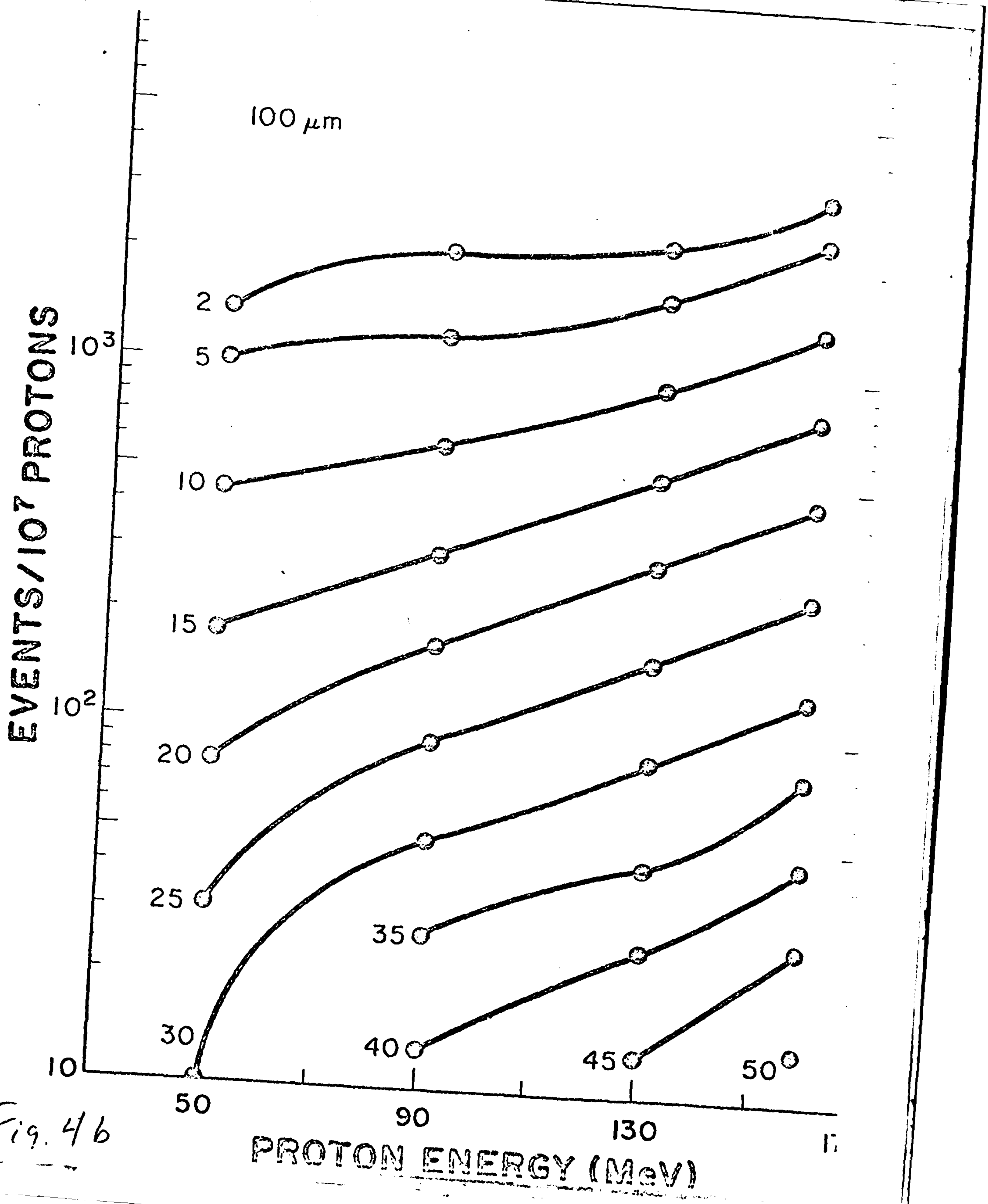


Fig. 4a



100 μm
EVENTS/10⁷ PROTONS
10³
10²
10
2
5
10
15
20
25
30
35
40
45
50°
50
90
130
PROTON ENERGY (MeV)

Fig. 4b

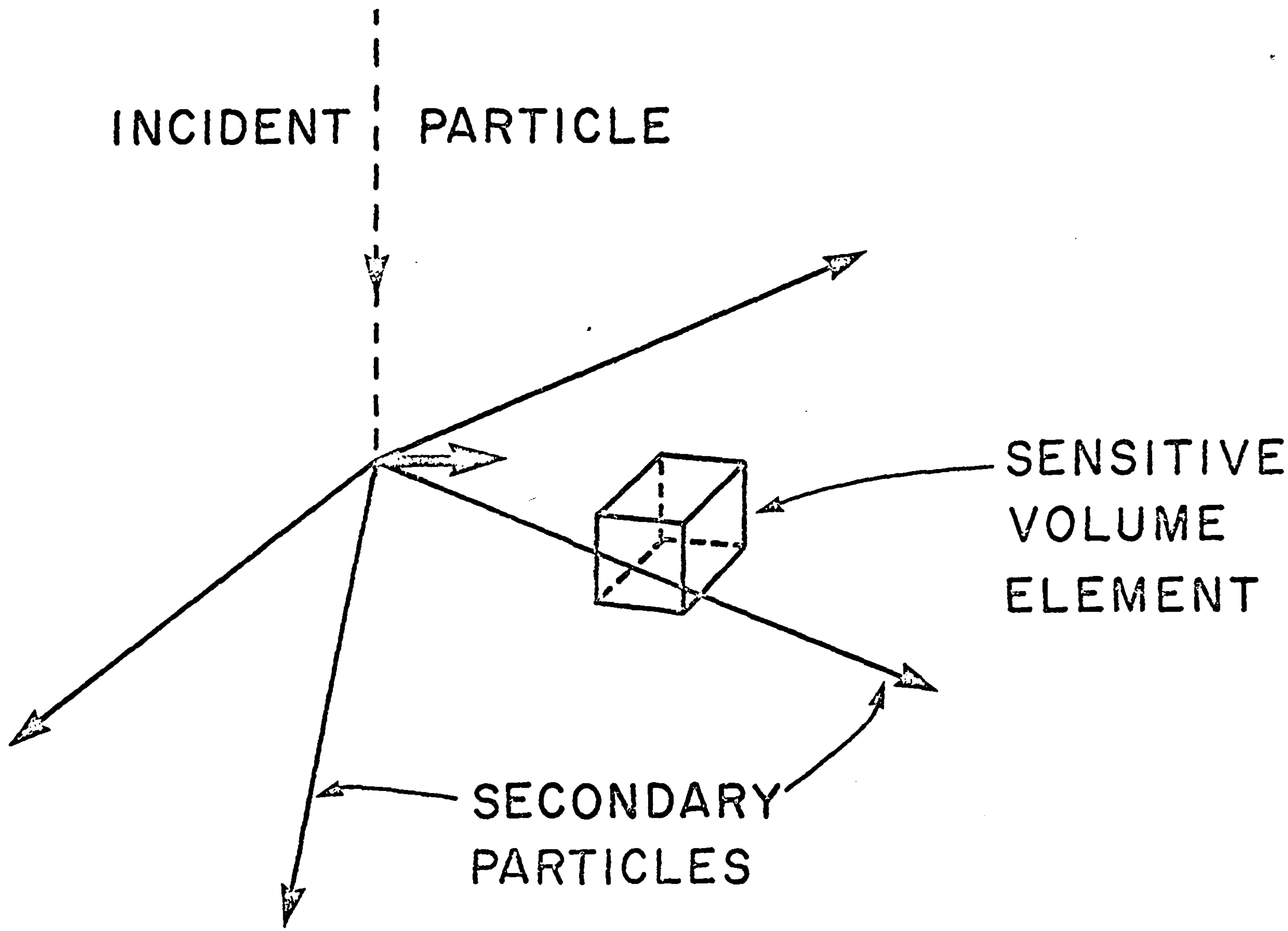

INCIDENT PARTICLE
SENSITIVE
VOLUME
ELEMENT
SECONDARY
PARTICLES

Fig. 5

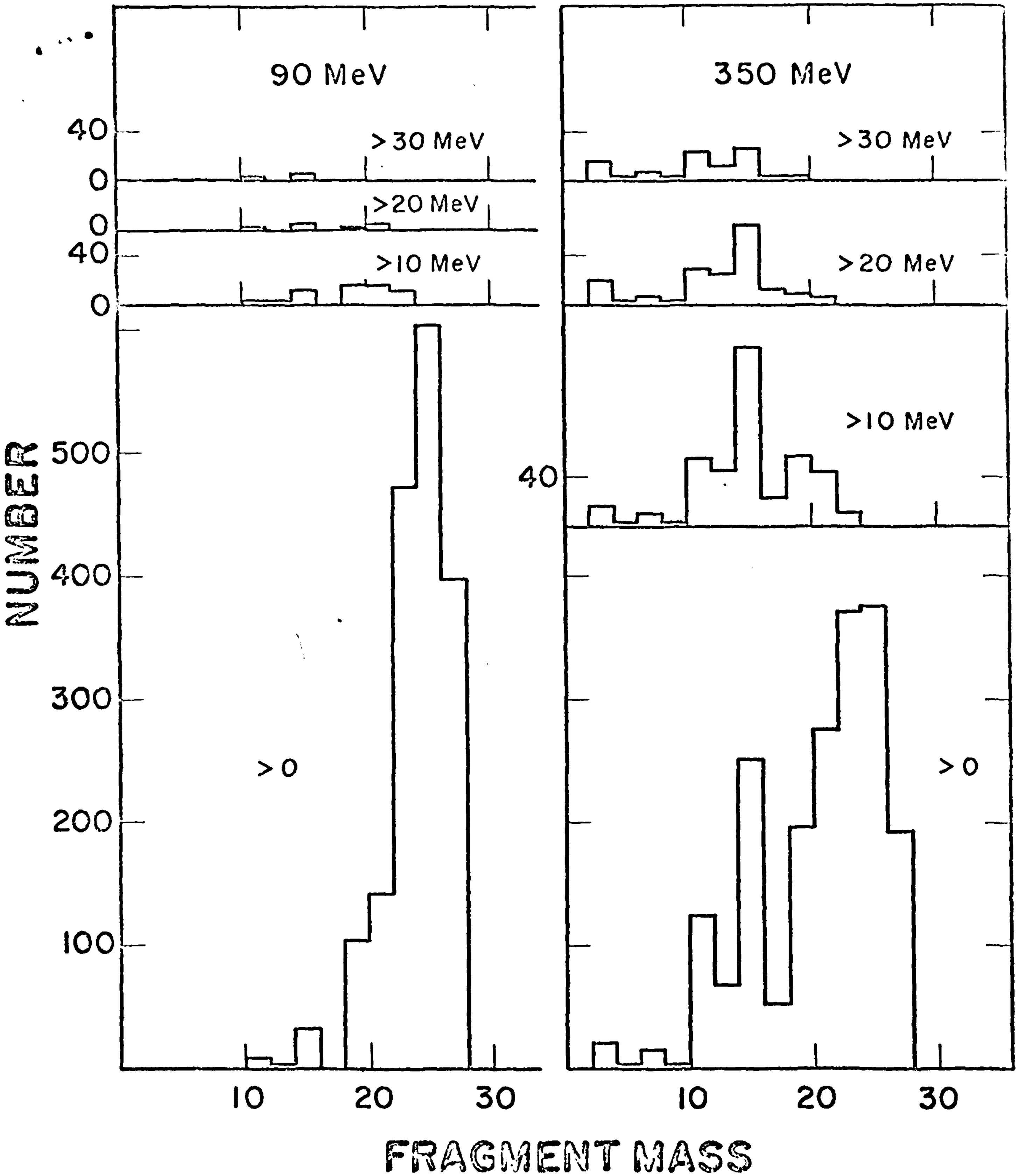

90 MeV
350 MeV
>30 MeV
>20 MeV
>10 MeV
>0
40
0
500
400
300
200
100
NUMBER
10
20
30
FRAGMENT MASS

Fig. 6

END

DATE
FILMED
10-81

DTIC

AD-A104 433 CLARKSON COLL OF TECHNOLOGY POTSDAM NY F/G 4/1
MICRODOSIMETRIC MEASUREMENTS ON NUCLEAR INTERACTIONS.(U)
JUL 81 P J MCNULTY N00014-81-K-2011

UNCLASSIFIED NL

2 2

SUPPLEMENTARY INFORMATION

END
DATE FILMED
1 82
DTIC

SUPPLEMENTARY

INFORMATION

AD-A104 433

Clarkson

September 2, 1981

Dr. C. S. Guenzer, COTR
ATTN: Code 6611
Naval Research Laboratory
Washington, D.C. 20375

Microdosimetric measurements on nuclear interactions

RE: SFRC No. N00014-81-K-2011

Dear Dr. Guenzer:

Please find enclosed one copy of two separate figures that were omitted from a Quarterly Technical Report for the captioned grant, which was sent to you on August 19, 1981.

We apologize for this error and appreciate your cooperation in this matter. Should you need any further information, please contact me at the number below.

Thank you.

Sincerely,

B. J. McKenzie

Bonnie J. McKenzie
Associate Director
Division of Research
(315) 268-6469

BJM/la
Enclosures

cc: Dr. McNulty
M. Morris
NRL Code 2627 (6)
DTIC Code S47031 (12)

81 9 09 006

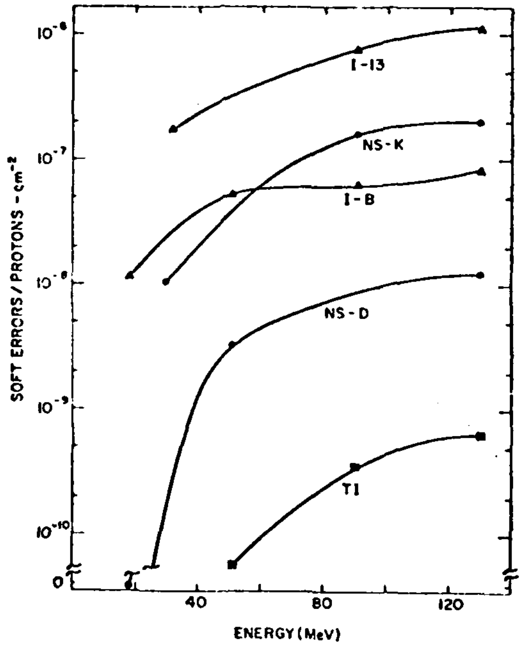


Fig. 1 Soft Error Cross Section versus incident proton energy. Curves labeled I represent Intel dynamic RAMs; those labeled MS represent National Semiconductor dynamic RAMs; and TI represents Texas Instruments static RAMs.

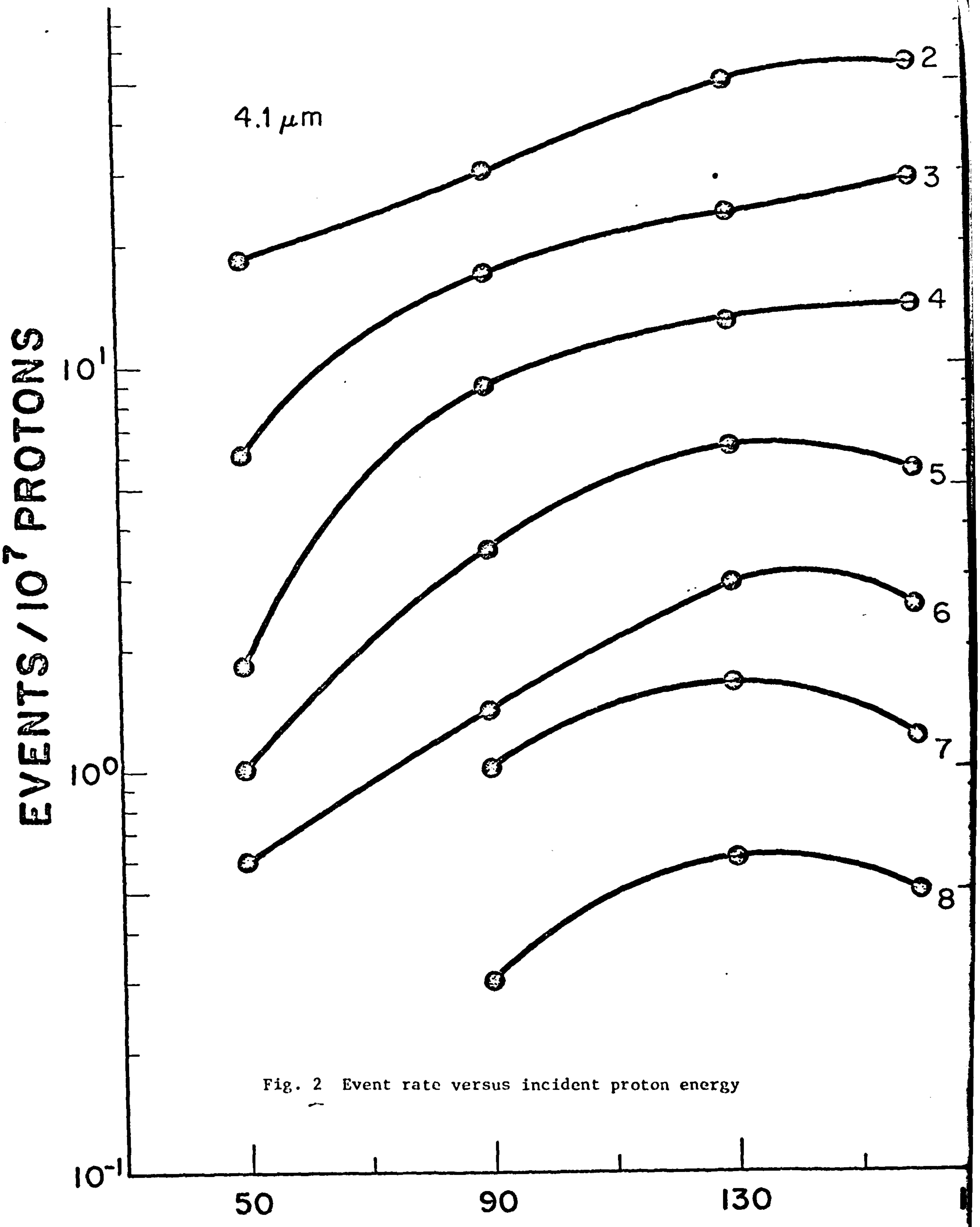


Fig. 2 Event rate versus incident proton energy

DAT
FILM